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Review Paper

A systematic review of methods for studying the impacts of outdoor recreation on terrestrial wildlife

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ABSTRACT

Outdoor recreation is a known source of disturbance to many wildlife populations. We systematically reviewed 126 relevant papers that study the impact of outdoor recreation on wildlife, focusing on terrestrial wildlife (birds excluded) to assess the different methodological approaches adopted by researchers. We characterised the research methods into seven categories (direct observation, indirect observation (field-based), telemetry, camera traps, physiological measurement, trapping, and simulation). We find that direct observation is the most commonly used method to capture human-wildlife interactions, followed by the use of telemetry, and camera traps. The animals most commonly studied were ungulates, and the orders Carnivora and Rodentia. Studies typically captured data over longer periods (median 54 months) when using trapping methods; other methods exhibited shorter study durations (median 22 months). The size of the animal under study appears to influence how methods are chosen, with larger species often being studied using telemetry methods. We highlight advantages and disadvantages of each method depending on the aims of the study, the focal species, and the type of outdoor recreation. Our review highlights the need for simultaneous measurements of both human activity and wildlife response. We also recommend that researchers consider how to capture both short- and long-term impacts on animal welfare. Our findings should guide applied wildlife conservation and management research in scenarios where human-wildlife interactions lead to conservation issues.

1. Introduction

Interactions between humans engaged in outdoor recreation and terrestrial wildlife are a conservation and management challenge because these activities can influence wildlife in many ways (Frid and Dill, 2002). For example, the impacts of

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outdoor recreation on wildlife are frequently unintentional (Bateman and Fleming, 2017; Larson et al., 2016). As human impacts on terrestrial wildlife continue to increase (Tucker et al., 2018); understanding the effects of outdoor recreation on wildlife is crucial to wildlife management. However, there is little evidence about which techniques are most suited to gathering data on such interactions, or which techniques are appropriate for particular animals, activities, and environmental conditions.

Disturbance by humans engaged in outdoor recreation can impact on wildlife in ways comparable to predation (Frid and Dill, 2002). These include effects at the individual level, such as increased vigilance (Langbein and Putman, 1992), fleeing behaviour (Ydenberg and Dill, 1986), change in habitat selection (Filla et al., 2017), reduction in fitness (Creel et al., 2002), parental investment (Gill et al., 2001), effects on energy expenditure (Houston et al., 2012), resource acquisition, animal condition and reproductive success (Frid and Dill, 2002). Over time and space, these individual effects scale up to become population-level pressures (Sutherland, 1996). However, outdoor recreation may also have a positive impact on some wildlife; for example, they can create corridors through vegetation or snow. Belotti et al. (2012) show that the lynx (*Lynx lynx*) can make use of tourist trails for hunting during night hours when levels of human activity are low.

The relationships between outdoor recreation and wildlife are complex and the ways in which data about human-wildlife interactions are collected will influence the analysis and understanding of these impacts. It is essential to choose an appropriate field method to capture how wildlife are impacted by outdoor recreation, for example avoidance responses (e.g. distance flown), time budgets or physiological responses (Bateman and Fleming, 2017); and doing so remains a major practical challenge for research on human-wildlife systems. The choice of field method will often depend on the taxa studied. Collecting data across a range of animal species, from rodents such as red squirrel (Haigh et al., 2017) to large mammals such as bears (Goodrich and Berger, 1994; Ordiz et al., 2013) can be a logistical challenge. Moreover, many species may be simultaneously influenced by a given outdoor recreation activity, yet respond in different ways (Rogala et al., 2011). Issues also arise from the wide range of outdoor recreation activities and the varied influences that they may have on wildlife (Gander and Ingold, 1997; Schnidrig-Petrig and Ingold, 2001). Thus, a comparison of the effectiveness of chosen field methods (e.g. to estimate population size) is rarely performed (Pfeffer et al., 2017; Wearn and Glover-Kapfer, 2019).

To address these challenges, a wide range of methods are used to study human-wildlife interactions. Direct observations of the animal's behaviour or position have been used to study habitat selection (Jayakody et al., 2008), movement (Nellemann et al., 2010), or dispersion (Lowney, 2011) related to human presence (Lima and Zollner, 1996). In the field of outdoor recreation, remote tracking devices have been used to study animal movement, with GPS devices increasingly deployed to investigate habitat selection (Marchand et al., 2014) or behaviour (Naylor et al., 2009). Camera traps are widely used to study human-wildlife interactions as they are used to locate and estimate population size, and also to examine interactions between different animals (Ladle et al., 2018). Physiological measurement, derived from blood (Romero and Wikelski, 2002), hair (Barja et al., 2007) or dung samples (Creel et al., 2002), are used to study the state of an organism, especially in relation to potential stressors like interactions with humans. Traditional trapping methods have also been used to sample populations and estimate size and demographic parameters, but these studies are not necessarily related to human disturbances (Havmøller et al., 2019; Royle et al., 2013).

Previous systematic reviews studied the interaction between outdoor recreation and wildlife but their main focus was to look regional differences in the impacts of outdoor recreation activity on wildlife (Bateman and Fleming, 2017; Larson et al., 2016; Sato et al., 2013), or on other ecological characteristics of the landscape (Marion et al., 2016). One particular study, has reviewed the impacts of outdoor recreation activity specifically on birds (Steven et al., 2011). These previous reviews, while providing thorough overviews of the taxa and types of disturbances that have previously been studied, do not provide a comprehensive review of the actual field methods that are being used to study outdoor activities and terrestrial wildlife interaction. Thus, the objective of this paper is to systematically review different types of field and data collection methods to guide research design decision in future research projects. Specifically, we compare the methods across different taxa, types of outdoor recreation activity, and by study objective; and we make recommendations about the advantages and disadvantages of different methods in different contexts. The structure of the paper is as follows: first, we evaluate 126 papers identified via a systematic review of the literature. Next, we present our results and discuss the advantages and disadvantages of each method. Finally, we provide five recommendations that researchers should consider when choosing a method to study human-wildlife interactions involving outdoor recreation.

2. Methods

2.1. Literature search

We performed a two-step search of the literature. First, we reviewed 100 papers obtained by searching in Web of Science "all databases" (Databases: Web of Science core collection (1900-present), BIOSIS Citation Index (1926-present), BIOSIS Previews (1969-present), Current Contents Connect (1998-present), Data Citation Index (1900-present), Derwent Innovations Index (1963-present), KCI-Korean Journal Database (1980-present), MEDLINE® (1950-present), Russian Science Citation Index (2005-present), SciELO Citation Index (2002-present), Zoological Record (1864-present)) using simple keywords (e.g. "recreational activity" or "wildlife recreational interaction") and by searching in the bibliographies of the papers we found. Second, from the initial pool of 100 papers, we identified key topics and themes in studies of human-wildlife interactions, which allowed us to develop a more complete keyword search phrase to use in a systematic search of Web of Science (same

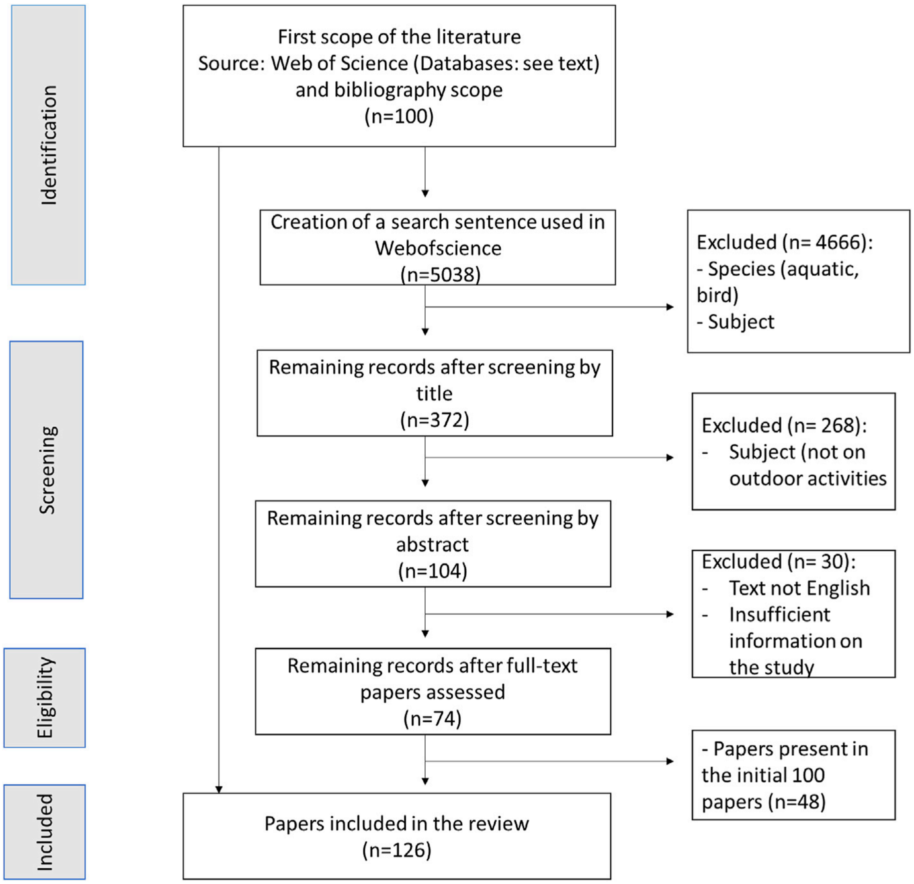

Fig. 1. PRISMA literature search flow diagram: The number of studies that were located, retained, and discarded are shown at each stage of the literature review process.

databases than above). We tested multiple search phrases and selected the one which produced the maximum number of matches with our initial 100 papers. This final search string was: (wild* OR mammal* OR animal OR carnivore OR herbivore OR predator OR reptile OR terrestrial* OR vertebrat*) AND (interaction OR conflict* OR disturb* OR coexist* OR encounter OR harassment OR displacement OR alteration) AND ("recreational activit*"OR bikes OR biking OR "horse riding" OR "wildlife watching" OR skiing OR skiers OR "winter activit*" OR climbing OR climbers OR trail OR jogging OR joggers OR weekend OR ATV OR "off-road vehicles" OR "off-highway vehicles" OR "off-road recreations" OR "over-snow vehicles" OR "snow-kiters" OR snowmobiles OR walkers OR walking OR hikers OR hiking OR hillwalkers OR hillwalking OR paragliders OR paragliding OR hunting OR hunters OR camping OR campers OR "outdoor activities") NOT (fish* OR sea OR amphibian OR marine OR bird) NOT (disease OR zoonot* OR infe* OR pathogen* OR vet* OR medic* OR chemi* OR neuroscience OR pharma* OR drug OR molec* OR contamin*).

This final search was conducted in Web of Science (core collection) on 10-01-2019 with no date restriction. The search returned a total of 5038 papers, including 48 papers from our original set of 100 papers (see Fig. 1). The absence of 52 papers from the initial pool can be explained, at least partially, by the use of bibliographies in the first stage of the search, which made it possible to gather papers absent from the Web of Science database. From the 5038 papers obtained from our systematic search term, we performed a three-stage assessment of whether to include the papers in our final review: i) selection by title (372 papers relevant), ii) selection by abstract, and iii) selection by content. During the screening of the title and the abstract we excluded papers that were irrelevant based on the study focus (i.e. not on outdoor activity) or when the species studied were not terrestrial (i.e. bird and aquatic animals). In the abstract selection phase, we retained papers for content screening when the abstract was closely related to our stated topic. After the final stage of screening by content, 30 of the 104 papers were removed from further analysis. In some cases, this was because, while the abstract was in English, the main text was in another language (as the authors needed to deeply understand the methods used, only English written papers were selected, despite the potential relevance of the paper), or because the text had insufficient information on the study to allow it to be included. We removed at every stage papers where the focus was on hunting impacts and papers where the animal was the primary focus of the outdoor recreation, such as many ecotourism studies where the animal is purposefully targeted by visitors, for example, during a safari. Thus, in addition to the 100 papers that we identified previously, our systematic search of Web of Science found a further 26 papers to include in our review dataset, giving a total of 126 papers.

To assess the comprehensiveness of our method we compared our final list of 126 papers to those used by (Larson et al., 2016) who review global impacts of outdoor recreation activity on wildlife. We compare the two systematic review reference lists by excluding references to birds, aquatic wildlife, ecotourism and hunting from the Larson et al. (2016) review and by excluding references post-2015 from our list. We found that our reference list comprises 80.3% of those references present in the Larson et al. (2016) analysis and 45 papers (35.5% of our list) that were not present in Larson et al. (2016). Thus, while our search did not include all the papers present in the Larson et al. (2016) analysis, we have also added references previously not included in their review. Because we focus specifically on the methodological challenges of implementing studies of human disturbance to wildlife, our work is therefore highly complementary to that of Larson et al. (2016) and our reference lists have substantial overlap.

2.2. Analysis of the literature

Eight methodological parameters were extracted from each of the 126 papers identified by our systematic review process:

1. Country where primary data were collected.
2. Year of publication.
3. Method(s) used to collect data (see Table 1).
4. Target species (classified by taxonomic order).
5. Type of outdoor recreation (as described in the paper, aggregated to categories we defined; see Table 2).
6. Aim of the study (e.g., behaviour, stress, spatial distribution).
7. Duration of the study (estimated in months).
8. Animal size (derived from Smith et al., 2003; Feldman et al., 2016; Brooks et al., 1992).

We attempted to categorize methods based on the literature and tried to use the most common term for similar/synonymous methods. We acknowledge that some of the methodological categories are more distinct than others, for example, the use of camera traps can also be considered as an indirect observation method. However, we consider that each of the categories of methods as described in Table 1 are unique in terms of how they are deployed in the field and further in the subsequent types of analyses that are conducted with the collected data. Many papers explore several species, multiple recreational activities, or use multiple data collection methods. Each was classified as a separate observation and therefore one paper could generate multiple observations in our dataset. Thus, from the 126 papers, 214 separate records were obtained.

We then used the three categories from Bateman and Fleming's (2017) measures of animal response to outdoor recreation:

1. Avoidance response: comparison of the animal presence or escape behaviour (changing residency patterns, alert distance, Flight Initiation Distance and distance fled) depending on the human activity.
2. Time budgets: change in the level of vigilance and change in life pattern (foraging, resting).
3. Physiological and breeding responses: increase in heart rate, stress hormones or change in the immune system. Also includes reproductive success such as a reduction in body mass.

All analyses were performed using R version 3.5.2 (packages: tmap Tennekes, 2018, ggplot2 Hadley, 2017, ggpubr Kassambara, 2019) Nakagawa et al., 2019. We performed descriptive statistics using visual representations of the count of the eight parameters mentioned above (Nakagawa et al., 2019).

Table 1
Seven classes of methods used to collect data on human wildlife interaction.

Methods	Descriptions	Examples
Direct observation	An observer actively records the animal position, its behaviour or any type of relevant information relating to its activity	Record of flight or fright distances, vigilance, position
Indirect observation (field-based)	Track indicator of the animal presence and whether this changes over time. Compare different areas or distances from a disturbance to imply causal changes in spatial distribution of the animals	Dung counts or track counts (in natural media or on track plates)
Telemetry	Track the location of the animal using transmitters	VHF, GPS or satellite enabled collars, and vaginal implants
Camera traps	Detect variation in presence or abundance of the target species in different areas	Motion detection cameras (trail camera), thermal cameras
Physiological measurement	Physical state of the animal recorded	Hormone level, body mass, reproductive success, temperature using blood, hair or dung samples
Trapping	Evaluation of individual based data or population density estimates and how these vary temporally and spatially	Capture of an animal at a specific location
Simulation	Use previous data to simulate the interaction between wildlife and recreation activity. Does not necessarily involve field-based deployment. However, this category is often conducted with another method, which provides the data to parameterise the simulation	Prediction of conflict zone

Table 2
Six types of outdoor recreation (human disturbance). *For our purposes, winter sports were considered separately from human foot traffic, non-motorised and motorised vehicles, because winter conditions can influence the choice of a method and the speed of travel differs from the other categories.

Types of outdoor recreation	Examples
Human foot traffic	Walker, hiker, camper, climber, tourist and visitor
Non-motorised vehicles	Mountain biking, paragliding and snow-kiting
Motorised vehicles	All-terrain vehicles (ATVs), off road vehicles and snowmobiles
Winter sports*	Alpine and backcountry skiing
Infrastructure	Buildings (e.g. presence of a resort), path and trail networks around resorts and other infrastructure
Pets	Animal with the recreationist (typically a dog or horse)

3. Results

In this section we present the results from our search and discuss advantages and disadvantages of each method.

3.1. Country of study

The majority of the studies we found were conducted in North America (USA; 54 and Canada; 11) (Fig. 2). Other regions with multiple studies included countries of western Europe, such as Norway (9), Switzerland (6) and the UK (6). The geographical trends in our study mirror patterns evident in other field-based studies in ecology as we focused only on the academic literature and specifically the English-language academic literature (Martin et al., 2012; Larson et al., 2016).

3.2. General temporal trends

The earliest paper identified in our search was published in 1979 (Fig. 3.a). The volume of papers published on the topic of outdoor recreation and wildlife increases noticeably from the year 2000. The maximum number of papers published in a single year was 13 (in 2013). Research investigating interactions between wildlife and outdoor recreation has increased over the last 40 years. This increase may be due to the increased availability of technology to record these interactions. The diversity of methods used also increased from the year 2000. Additionally, outdoor recreation is increasing (Cordell, 2008) and human concern about the impact is also increasing. It might also be due to the rate of growth in terms of papers published over time on the subject which follows a similar pattern to the general rate of growth of publications in science (Larsen and von Ins, 2010). Here again, these results align with previous literature reviews on the subject of outdoor recreation and wildlife (Larson et al., 2016).

3.3. Methods used and description

We looked at how methods used to study human-wildlife interaction have changed over time, recognising that data collection would have occurred prior to publication dates, but here we show only publication date. Direct observation was the most commonly used method (41%; Table 3). It was first used in 1979, with a constant increase up to a peak in 2003, after which the use of direct observation reduces relative to other methods (Fig. 3.b.). Direct observation, was likely preferred in early years because, as a tool for studying wildlife behaviour, it has a low barrier to entry in terms of equipment requirement and set-up costs. However, behavioural observation can be time-consuming and therefore costly because observations require the presence of a scientist or trained observer to record behavioural measurements such as movement rates, vigilance, prey intake rates, and parental care (Gill et al., 2001). Thus, direct observation can provide high quality data at high resolutions but is costly in terms of human time commitment, which can limit sample sizes. Moreover, observer presence, itself, can cause a disturbance. The decrease in use of direct observation is likely to have resulted from technological advances that reduced reliance on direct observation. For example, telemetry methods exhibit a marked increase in the 2000s and the 2010s, coinciding with the development of GPS tracking technology.

In our review, telemetry was the second most used method (25%; Table 3). The use of GPS collars allows researchers to compare the distribution of animals depending on the presence or absence of a stressor, such as how ungulates distribute themselves in relation to hiking trails on weekdays (less disturbed) compared with weekends (more disturbed) Sibbald et al., 2011. However, without such an experimental set up, telemetry by itself only provides information on animal movement, not on what is causing this movement. For example, disentangling the effect of the outdoor recreation from environmental effects such as the weather, habitat, or presence of other wildlife species requires multiple, independent data layers and advanced statistical analyses (Coppes et al., 2017).

This increase of research using telemetry and camera traps after 2000 aligns with previous studies looking at the adoption of these methods more generally in ecological studies (Kays et al., 2015; Wearn and Glover-Kapfer, 2019). Camera traps were used in 13% (Table 3) of the papers we identified. Camera traps have a distinct advantage in that they provide a straightforward approach for studying multiple species simultaneously using a single setup. For example, some of the research reviewed here used camera traps to study interactions between animals (Ladle et al., 2018) or within communities (Kays et al.,

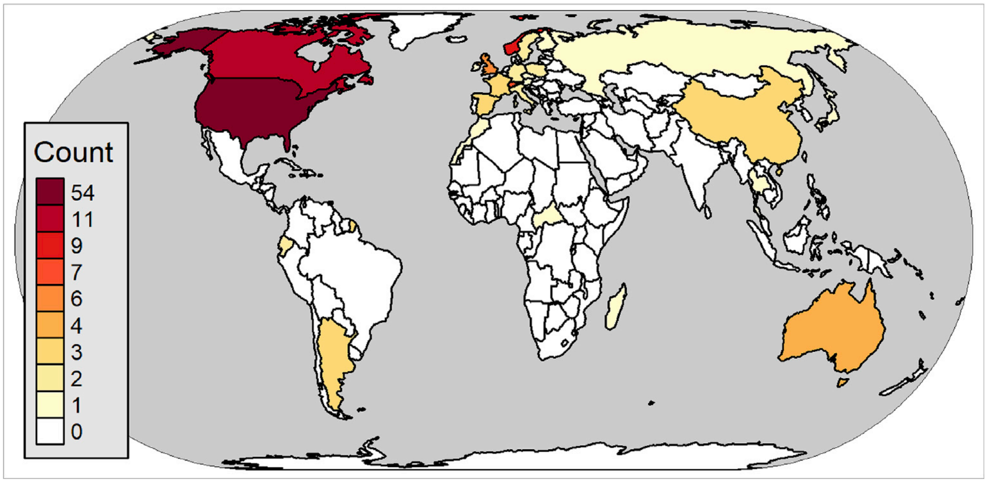

Fig. 2. Geographical distribution of the number of papers studying the interaction between wildlife and recreationists per country.

2017), depending on the presence or absence of different types of outdoor recreation. Wearn and Glover-Kapfer (2019) compared camera trap detection efficiency with other methods and found that camera traps were more efficient at detecting animals than other methods (e.g. live and hairs traps), especially for large animals. Camera traps can be deployed over large areas and used for long durations with relatively minimal ongoing field effort for data collection (O'Connell et al., 2011). However, camera traps can generate large numbers of photos, leading to significant analytical time considerations. Machine learning, automatic classification of the photos and image analysis using citizen science are current solutions to this specific issue (Locke et al., 2019; Norouzzadeh et al., 2018). Once images have been classified, new statistical methods allow

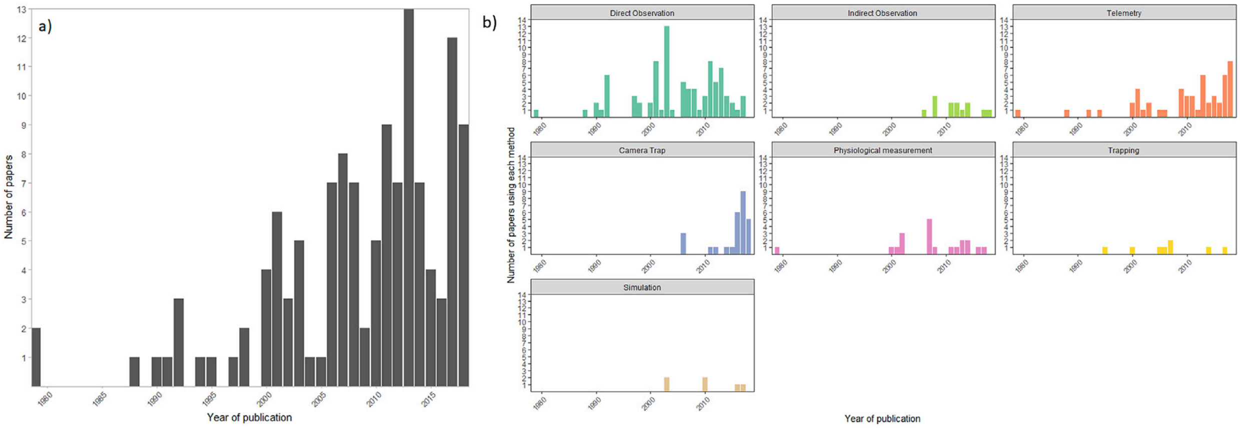

Fig. 3. a) Number of papers in our sample on wildlife-recreation interaction published per year. b) Number of papers using each method per year. Each paper can use several methods; for example, in 1979 there were only two papers in our data set (Fig. 3a) but one of these papers used two different methods and, thus, it contributes to three data points in this chart.

Table 3
Number of records for each category of method.

Method categories	Number of records	Percent
Direct observation	87	41
Telemetry	53	25
Camera Trap	27	13
Physiological measurement	20	9
Indirect observation	13	6
Trapping	8	4
Simulation	6	3
Total	214	100

estimation of occupancy and abundance from camera trap data, which can be linked to the presence of outdoor recreation (Parsons et al., 2016; Reilly et al., 2017). Following Wearn and Glover-Kapfer (2019), we propose that camera traps are likely to become more prominent for studying human-wildlife interactions, especially with the development of sophisticated analytical methods (e.g. automated image processing).

Physiological measurement methods were used from 1979, but were not widely applied until 2000. Physiological measurement methods (9% of the papers analysed here) have been used to understand the biological response mechanism and the consequences for the animal (e.g. reproduction, weight, survival, access to food, predation risk, disease risk, reduced immunity). In particular, the use of glucocorticoid hormones has become increasingly common (Barja et al., 2007; Romero and Wikelski, 2002; Zwijacz-Kozica et al., 2013). Glucocorticoid hormone secretion is an animal response to stress and is known to occur in wildlife as a result of interactions with humans. In the short-term, the release of these hormones can be beneficial for the animal as it allows energy mobilisation Rehnus et al., 2014; it is a normal adaptive response to avoid a negative situation such as predation avoidance (Romero and Wikelski, 2002). However, in the long-term, hormone secretion can cause pathologies such as reproductive disruption or suppression of the immune system, which reduce fitness (Creel et al., 2002). Blood, faecal and tissue samples (e.g. hair or skin) can be used to measure glucocorticoid hormone levels. While blood samples provide more accurate results (Romero and Wikelski, 2002), the use of faecal samples is less disruptive and easier to set up (Barja et al., 2007). Blood samples give an instantaneous indication of stress levels, while tissues such as hair reflect stress levels over the period of time that the tissue has been growing. Other demographic methods (included with physiological measurement here) involve studying reproductive success by looking at the number of young per adult (Burger et al., 2007), infant mortality rates (Berman et al., 2007), heart rate (MacArthur et al., 1979) and demographic data (Griffin et al., 2007). These approaches are often specifically related to a targeted question but make it possible to analyse longer-term impacts on the population as they relate to the fitness of the individual and population. These longer-term assessments are necessary to deeply understand the potential impact of recreationist on wildlife.

Indirect observation (field-based), trapping, and simulation were the least frequently used methods (respectively 6%, 4% and 3% of the papers studied) (Table 3), appearing only in more recent years (Fig. 3.a.). Indirect observation methods, such as footprints/tracks, can be used to locate animals in relation to the presence of outdoor recreation (Zhou et al., 2013) and have the advantage of being non-invasive. However, it may be difficult to estimate when an animal was present via indirect observation methods. For example, Reilly et al. (2017) argued that the use of scat as an indicator was not reliable for the study of the impact of recreational activities as dogs may eat or displace scat and lead to an underestimate of population size. The presence of scat and footprints do not necessarily imply disturbance because some animals naturally congregate along paths. Moreover, the use of indirect observation can generate uncertainty, for example in identifying species from scat samples or footprints. In some cases, the use of specialist and potentially costly DNA analysis to identify species can be conducted (Reed and Merenlender, 2008). Animal abundance is also difficult to establish through indirect observation: all else being equal, the number of – e.g., tracks – left in the environment should increase linearly with the number of individuals moving around the environment (Stephens et al., 2006). However, animals move different distances at different times and under different conditions and produce different amounts of dung with different decay rates according to diet and conditions (Hayward et al., 2015). Another issue might be in landscapes where the intensity of outdoor recreation is relatively high and may directly impact the ability to detect wildlife using indirect methods (e.g. tracked out ski areas). The future development of telemetry, camera traps, and simulation could lead to a decrease in the use of traditional field methods such as direct observation, indirect observation, and trapping.

Trapping methods have a traditional place in field ecology, particularly as a basis for long-term studies. For example, Iverson et al. (2006) used trapping over a 25-year period to study the impact of the increase in tourism on Allan Cays Rocks Iguanas. Similarly, Garber and Burger (1995) studied turtle population sizes related to recreational activities for over 20 years. Overall, trapping was mainly used to perform capture-recapture type analyses, and primarily for the study of reptiles (Iverson et al., 2006; Sato et al., 2014) and small carnivora (Slauson et al., 2017) (see results below). This might be due to the main advantage of trapping which is its low cost in terms of equipment (but it can be intensive in terms of researcher hours).

In more recent years simulation methods are increasingly being employed. The volume of reliable data collected in the field is now reaching the point where enough underlying data exist to develop rule-based algorithms to simulate different processes and interactions. Hence, simulations of human disturbances of wildlife are likely to increase. For example, Enggist-Dublin and Ingold (2003) used existing data to develop a mathematical model to simulate wildlife disturbance and to compare the potential impacts of hikers and paragliders on wildlife. The use of simulations has the advantage of being cost-effective in that it does not require the collection of new data and leverages previous investments in field data. Simulation methods are used to predict the effect of disturbance using data from other locations, for example, to predict conflict zones by expressing the normal and disturbed behaviours of the animal, its preferred habitat, and the level of disturbance (Goldstein et al., 2010). From our review, examples that use simulation relied on a variety of methods to collect underlying data, primarily tracking data (Goldstein et al., 2010; Musiani et al., 2010; Olson et al., 2017). Simulations make it possible to predict and map potential hot spots of human-wildlife interaction and, thus, to manage the interaction between wildlife and human a priori (Musiani et al., 2010).

We also found that 20% of the papers analysed (25 papers) use more than one method to capture data. Three papers used more than three methods at the same time. Telemetry was most commonly used in combination with other methods, particularly alongside direct observations. The use of multiple methods has the advantage of leveraging the benefits of each individual method. They can also be used to confirm and cross reference observations (e.g. triangulation for detection) or

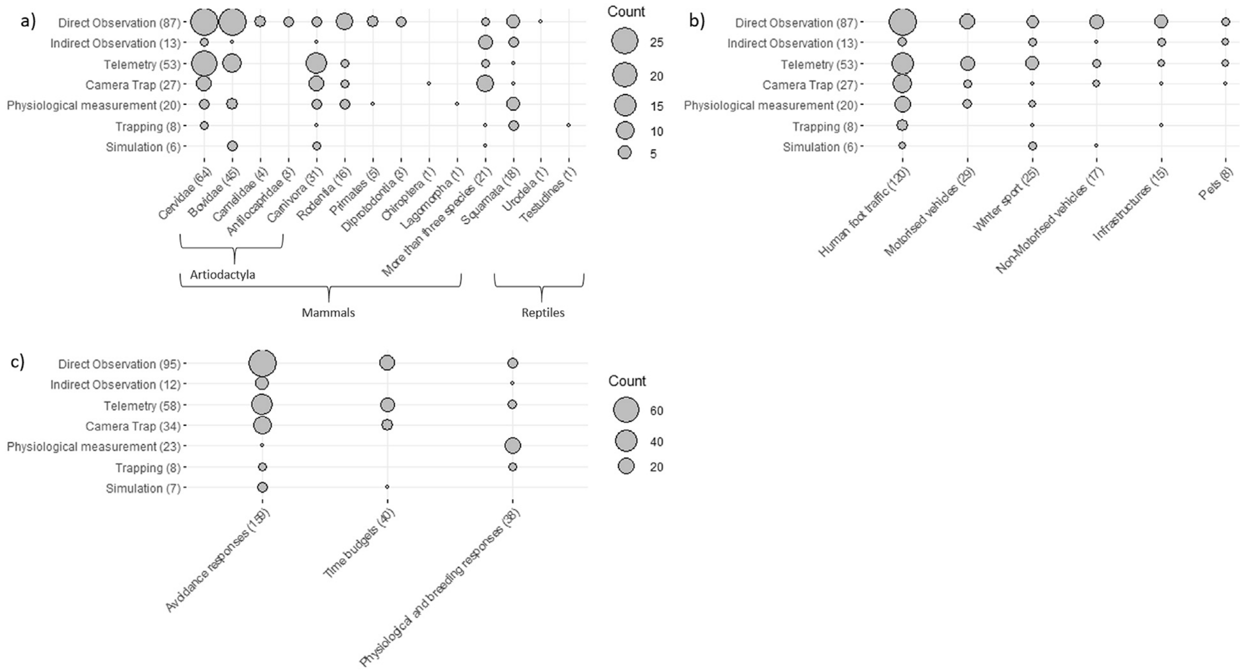

Fig. 4. Number of uses of each method (a) vs. animal order (b) vs. outdoor recreation categories (c) vs. the aim of each.

provide insight into different components of the animal response (activity change and physiological changes). For example, Creel et al. (2002) used telemetry to locate individuals and faecal samples to estimate glucocorticoid levels as stress indicators in an elk population. Another advantage of using multiple methods is that they make it possible to address multiple aims or to study multiple species. For example, Cassirer et al. (1992) studied behaviour and movement by combining telemetry with direct observation. This make it possible to understand how the outdoor recreation impact the wildlife at a large scale - a community of species in an area. Using multiple methods can pose challenges, notably additional costs in terms of equipment, field time and analytical complexity, but can be employed strategically to maximize findings from field efforts.

3.4. Method vs species

The most common order studied was the Artiodactyla: cloven-hoofed animals (116 records) (Fig. 4.a.) with mainly Cervidae (64) and Bovidae (45). Previous literature review also find the prevalence of Artiodactyla during studies of outdoor recreation and wildlife (Larson et al., 2016). Here, they were studied most often using direct observation (27 and 26 records respectively) or telemetry (23 records and 11 records respectively). While this might be due to the ease of observing larger animals, our analysis of animal size shows that direct observation was used for medium-sized animals while telemetry was mainly used for larger animals (see section 3.8. below). This is likely because, in earlier years, telemetry systems were relatively heavy, meaning only large animals could be fitted with the devices. The development of smaller tags makes it possible to use telemetry methods, even GPS units, on all sizes of animal (Kays et al., 2015) from small rodents (Haigh et al., 2017) to large ungulates (Harris et al., 2014).

The second most common order studied was Carnivora (31 records) and a variety of different methods were used, notably telemetry (14 records) and camera traps (7 records). Spatial tracking appears to be the primary aim when studying this order. Rodentia and Primates were the third and fourth most common orders studied (respectively 16 and 5 records), and they were primarily studied using direct observation (9 and 4 records each respectively) and physiological measurement (3 records for Rodentia). Studies of reptiles in the order Squamata were also well represented in the literature and involved a variety of methods (5 records with direct observation, 5 with physiological measurement, 3 with trapping and 3 with indirect observation but none with telemetry). Samples of blood (i.e. physiological measurement methods) were used to study Rodentia and reptiles more common than other animals, which might result from the ease with which they can be trapped for sampling. Finally, many papers study multiple species, with 21 records studying more than 3 species simultaneously. These papers typically used camera traps (9 records) or indirect observation methods (4 records).

3.5. Method vs outdoor recreation

The category human foot traffic was the main recreation studied; it was examined in 120 records. This result also aligns with Larson et al. (2016) findings and a prevalence of hiking and running as outdoor activities in interaction between wildlife and outdoor recreation studies. Our results make it possible to know that there are mainly studied using direct observation (47 records) (Fig. 4.b.). Motorised vehicles were investigated in 29 records, primarily through direct observation (12 records) but also using telemetry (10 records). The categories winter sports and infrastructure (25 and 15 records respectively) were studied using a wide range of methods, with mainly direct observation for the latter (7 records). The impact of non-motorised vehicles (17 records) was mainly studied using direct observation (10 records), and the studies of pets (8 records) were performed primarily using direct observation (3 records) and physiological measurement (2 records).

3.6. Method vs the aim of each study

Studying avoidance responses amongst animals was the most common study aim (159 records) which was mainly assessed using direct observation (72 records), telemetry (38 records), and camera traps (25 records) (Fig. 4.c.). The second most common aim was to observe a change in time budgets (40 records), where the three main methods used were direct observation (16 records), telemetry (14 records) and camera traps (9 records). Most studies of human-wildlife interaction using direct observation focus on movement rates (such as flight distance) and levels of vigilance (Gander and Ingold, 1997; St-Louis et al., 2013) as these metrics enable assessments of the habituation of animals to a disturbance (Bateman and Fleming, 2017). The predominance of direct observation to record movements and vigilance may be due to its ease of implementation in early years when other technology was either not available, unreliable, or prohibitively expensive.

Nowadays, GPS collars and other trackers can use 3D accelerometers to study the behaviour and vigilance of an animal (Kröschel et al., 2017; Naylor et al., 2009) and can also be combined with remotely-sensed weather and habitat data as well as studying interactions with other tagged animals (Kays et al., 2015). These features can be observed in real time, thus allowing changes in individual behaviour to be understood when animals approach a recreational area (Naylor et al., 2009). Multi-sensor tracking can also be used to study how different species of wildlife interact with one other when affected by human activity (Courbin et al., 2014). However, tracking involves capture to fit collars or tags which alters short term behaviour and may also have unintended consequences, such as endangering rare species that are subject to illegal trade if their locations are revealed through this technology. In this situation, less invasive methods, like camera traps, may be more appropriate (O'Connell et al., 2011).

When the aim of a study is to look at the impact of outdoor recreation on body mass and reproduction and survival, physiological measurement and trapping methods can be used. Physiological measurement method, as mentioned above are able to provide an indication of the physical state of the animal and trapping allows animal weight and body condition to be measured. However, trapping often use bait to attract animals (Slauson et al., 2017) which can affect movement behaviour and local residency time (Stewart et al., 2019), thus confounding analyses of the impacts of recreational disturbance.

3.7. Control site

In our review, the use of a control site was frequent (2/3 of the studies). Larson et al. (2016), in comparison, found 60.9% of their papers reviewed using this type of study design. In our review, one example, is in Haigh et al. (2017) levels of faecal cortisol metabolites in red squirrels were compared in areas with variable levels of disturbance and at different times of year. Comparing across sites with different levels of outdoor recreation is relevant if the areas are generally similar in terms of their other attributes. Comparing across time within a year can, however, be confounded by the presence of seasonal/life cycle factors or stochastic weather events (e.g. leading to starvation) that may be further impacted by human-disturbance. For example, faecal cortisol metabolite levels can be low in pregnant females or high in foraging males, making it difficult to disentangle seasonal variations from the effects of human disturbance, which also vary seasonally (Haigh et al., 2017).

All of the methods included in our study make it possible to estimate or analyse either the density of animals, their behaviour, their time budgets, or other physiological states of the animal. These observations can be compared with a control site by repeating the same experiment in comparable areas with differing levels of recreational activity (Neuhaus and Mainini, 1998). Many studies using paired/control sites contrast areas where visitor entry is restricted with recreational areas and, thus, the level of disturbance is treated as binary. In some cases, the level of disturbance and its effect on the wildlife can depend on the number of visitors and, thus, the level of disturbance was categorised as "less disturbed" and "more disturbed" areas (Sutton and Heske, 2017; Zhang et al., 2013). However, in the papers we reviewed, the characterisation of the outdoor recreation disturbance and more specifically its quantification was often unclear. Binary area and categorical level of disturbance provide some basic information but the quantification at finer scales (e.g. numerical count, recreationist tracking) is necessary to provide efficient management guidance (Larson et al., 2016).

3.8. Study duration and animal size

The mean duration of studies was 25.4 months (±44.6), with a minimum of 0.06 months (2 days) and a maximum of 288 months (24 years) (Fig. 5.a.). Trapping methods were typically associated with longer duration studies and had the greatest

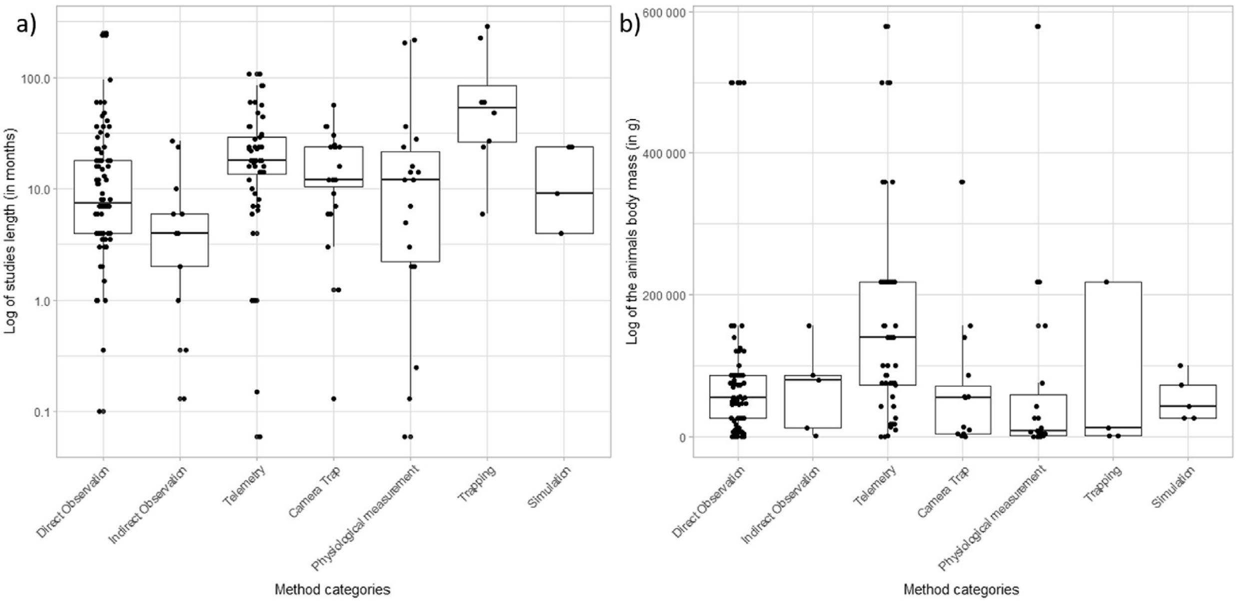

Fig. 5. Method used depending on a) the duration of each study b) the body mass of the animal.

median duration. The median duration and range of study durations was very similar across other methods. Only 36% of the records used any sort of control (spatial or temporal). Larger animals were studied using telemetry (Fig. 5.b.), which can be explained because this method requires sensors to be carried by the animal. Trapping and physiological measurement methods were associated with small animals, such as rodents.

4. Discussion

4.1. Guidelines for studying interactions between humans and wildlife

A variety of methods can be used for studying human-wildlife interactions in the context of outdoor recreation and each has particular advantages and disadvantages. From the literature, we developed a list of criteria and sub-criteria that a researcher should consider when developing a research strategy for collecting data on wildlife to study their interaction with recreationalists (Table 4). These criteria are not meant to lead deterministically to specific techniques, but rather to serve as an advisory checklist to undertake before starting a study. This checklist voluntarily restricted the number of method at maximum two per sub-criterion, meaning we identified, at a maximum, the two best data collection methods associated with each criterion and sub-criterion. This short selection of method aims to help research in their method choice but inevitably, this is a trade-off between the advantages and disadvantages of each method, financial and logistical issues, and the specific questions that the study aims to address.

4.1.1. Criterion 1: study objective/wildlife response to disturbance

Methodological decisions should be informed by the aim of the study (Table 4, Criterion 1). Here, we argue that the objective of the study is typically closely aligned with the hypothesised response of the organism to disturbance. For example, Jayakody et al. (2011) studied the diet of red deer in relation to outdoor recreation and thus use faecal sample, an adequate method, to obtain dietary information. Researchers should always explicitly state what the hypothesised response to disturbance will be and how well this is known, particularly in relation to the predominant recreational activity under study.

4.1.2. Criterion 2: species

Choice of method depends on the study species (Table 4, Criterion 2), including whether the focus is on a single species or multiple species. The mobility, the density and the size of the animal are therefore an important part of the methodological choice. These parameters will influence the choice of the method as they influence the detectability of the animal, the suitability of different technology, or the availability of existing knowledge of a hypothesised response.

4.1.3. Criterion 3: outdoor recreation

The most appropriate method will certainly depend on the type of outdoor recreation that is being studied (Table 4, Criterion 3). An important decision is how to record the activity component of the study: i.e., how will the outdoor recreation be captured and what aspect of recreational disturbance will be considered? In our review, few studies recorded the position

Table 4
Methods (D.O: Direct observation; Tel.: Telemetry; C.T: Camera traps; Phy: Physiological measurement; I.O: Indirect observation; Tr: Trapping; S: Simulation) depending on the different criteria (1) Study aim, (2) Species, (3) Outdoor activity, (4) Habitat, (5) Logistical. For each criterion we highlight a maximum of two methods considered as optimal for each sub-criterion.

			Potential methods						
			D.O.	I.O.	Tel.	C.T	Phy.	Tr.	S.
Criterion 1: Study Aim	Avoidance response (1): comparison presence/absence depending on level of disturbance					✓		✓	
	Avoidance response (2): Escape behaviour (e.g. alert distance, Flight initiation distance)		✓						
	Time budget (time allocation of activities)		✓		✓				
	Physiological and breeding response	Increase in stress level					✓		
		Impact on fitness (mating success and reproductive rate)					✓	✓	
Criterion 2: Species	Multiple species studied					✓		✓	
	The species interact(s) with other animals in the study area			✓		✓			
	Mobility	Low					✓	✓	
		Medium	✓			✓			
		High			✓				✓
	Density	Low				✓			
		Medium				✓	✓		
		High	✓			✓			
	Size	Small					✓	✓	
		Medium				✓			✓
		Large			✓				✓
Criterion 3: Outdoor recreation	Human foot traffic		✓		✓				
	Motorised vehicles		✓		✓				
	Winter sport			✓	✓				
	Non-Motorised vehicles		✓		✓				
	Infrastructures					✓			✓
	Pets		✓				✓		
Criterion 4: Habitat	Temporal comparison		✓				✓		
	Spatial comparison				✓				✓
	High density vegetation (e.g. low visibility)						✓	✓	
	Change in vegetation coverage over season				✓		✓		
	Open landscape (e.g. tundra, moorland)				✓			✓	
	Isolate area				✓				✓
Criterion 5: Logistical	Study duration	Short	✓		✓				
		Long			✓				✓
	Low budget		✓						✓
	Low/No field assistance				✓				✓

of outdoor recreationalists while studying the wildlife response (i.e., a true two-way observation). For example, Olson et al. (2018) asked recreationists to carry GPS loggers to estimate recreation intensity while lynxes were simultaneously tracked via GPS. More commonly, the use of spatial and/or temporal comparisons with a control site are used to differentiate between different outdoor recreation intensities.

Our major recommendation regarding the link between method and outdoor recreation is to differentiate between static disturbances, such as infrastructure (where any type of method can be used), and mobile disturbance mechanisms such as motorised and non-motorised vehicles. The latter require methods such as direct observation, telemetry or camera traps to observe movement and reaction. For studying the impacts of winter sports, the use of camera traps can be limited as the lens can easily become covered by snow and, thus, we recommend alternative methods, such as telemetry (Olson et al., 2018).

4.1.4. Criterion 4: habitat

Habitat is a major determinant of the spatial distribution and behaviour of wildlife; thus, the structure of the local habitat is an important consideration when designing a study (Table 4, Criterion 4). Studying the impact of human disturbance on animal behaviour is often unreliable if the habitat is not also monitored (Gill et al., 2001). Gill et al. (2001) emphasise the importance of looking at shifts in habitat selection by the animals in addition to responses to disturbance when investigating human-wildlife interactions. Movement to another habitat represents a trade-off between the fitness cost of moving against the availability of another habitat: if another relatively suitable habitat is available the animal will likely avoid the disturbed habitat in favour of the alternative habitat. However, if no other suitable alternative habitat is available the fitness cost for the animal increases and a shift to another less disturbed but suboptimal habitat is not an inevitable choice, as it carries other potentially negative consequences.

A preliminary habitat assessment of the study area should help to guide the types of questions that may be important (from animal behaviour, human behaviour, and habitat selection perspectives), and the types of methods that may be suitable for capturing data on the hypothesised disturbance response under these conditions. For some methods, the density of the vegetation can be an important factor in study design as animal observations can be limited in high density cover, especially for small animals. For example, comparison of red squirrel density during winter and summer using direct observation is potentially biased due to the higher density of vegetation in the summer (Lowney, 2011). In open landscapes, such as tundra or moorland, a lack of cover means that poles used to mount camera traps or observer presence can influence animal behaviour. Habitat parameters need to be considered from short and long-term perspectives, contingent on the nature of recreation (e.g. permanent habitat change due to infrastructure development, temporary perturbation due to seasonal activities, or gradual/cumulative impacts on the ecosystem through prolonged recreation or increased visitor numbers). Each may have distinct effects on wildlife behaviour and are important for managing and mitigating potential human-wildlife conflict.

4.1.5. Criterion 5: logistical

Study constraints can also influence the choice of method (Table 4, Criterion 5). First, study duration is an important criterion to consider when choosing a method. The ability to demonstrate whether disturbance impacts are short- or long-term depends on the length of the study; different methods also have different advantages in their ability to characterize the temporal duration of the disturbance. The use of faecal samples can be used to predict spatial patterns of animal distribution that may arise from long term disturbance even if the length of the study itself is very short (Jayakody et al., 2008). Combining methods over time, such as by historical observations and more modern techniques, can lead to insights into longer term impacts of disturbance.

Budgetary constraints clearly affect the choice of method depending on whether researcher time or finances are the limiting factor. While some methods are more suitable for low budget research (i.e. in terms of equipment), they are also the most labour intensive in the field, which may pose increasing costs depending on the study area. Other factors may influence the choices researchers make, such as the accessibility of the field site, their proximity to the field site, and the available infrastructure near the field site. Inaccessible areas may not need a large workforce – just a lot of time from a small number of people. However, to our knowledge, no studies highlighted how their budget influenced their choices of methods, despite wide acceptance of the fact that budget often plays a major role in research design. The same applies to data analysis. This literature review does not assess how field data may be analysed post-collection, but some methods (e.g. camera traps) generate large quantities of complex field data with a relative low intervention cost, but require a substantive effort and data analysis skills in the post-processing phase.

4.2. Perspectives

The impact of disturbance on an animal becomes a conservation concern when reductions in survival or fecundity lead to population decline (Gill et al., 2001). Disturbance patterns can also influence an animal's ecological impact, for example by shifting browsing activity, and this is a particular consideration for species whose populations are managed to control their effects on the ecosystem. Thus, for conservation and management purposes, the identification of the stage at which disturbance shifts from having a short-term behavioural impact to a long-term impact is necessary. This will depend on the animal species and its sensitivity to the disturbance (Cooke, 1980), its adaptability (i.e. the animal can develop habituation, Hines, 2011), its surrounding habitat (Gill et al., 2001) and the strength of the disturbance (i.e. temporality and magnitude) (Neuhaus and Mainini, 1998). Some methods are more appropriate (i.e. physiology, trapping) for demonstrating long-term behavioural impacts than others (i.e. direct observation, telemetry, camera traps) as the maintenance of costlier methods for longer periods may not be considered cost-effective. Therefore, a key area for future research is to adapt remote tracking and camera trap methods to study the mechanism of stress caused by the disturbance. For example, supplementing a tracking approach with additional methods, such as physiological measures or simulation, may help to understand longer-term impacts. Importantly, making the distinction between short- and long-term impacts will help management and conservation groups and outdoor recreation activity stakeholders to identify trade-offs between the welfare of the animal, the condition of the habitat, and the practice of outdoor recreation. Understanding these trade-offs is crucial to reduce the potential for conflicts (Redpath et al., 2013).

A diverse suite of methods are currently being used to monitor wildlife interactions with outdoor recreation. However, most work has focused on the animal component of this interaction. Control areas with different levels of outdoor recreation are commonly used to describe the human disturbance component in a relatively simple way (e.g., high vs low intensity sites) which may not fully represent how people use the space. For example, signage may influence levels of 'off-trail' recreationalist behaviour (Bradford and McIntyre, 2007) but recreationalist-free areas can be difficult to identify or predict. Thus, comparing areas with and without formal recreational paths provides a partial and potentially biased indicator of human-wildlife interactions if human activity is insufficiently monitored. The use of more detailed observation methods of outdoor recreation activity (e.g., through observation, tracking or other means) is currently uncommon. To identify more clearly the disturbance effects of outdoor recreation and how this interacts with habitat factors, more emphasis needs to be placed on collecting detailed data (spatial and temporal) on the human behaviour component as well as recreational impacts on the habitat (e.g. availability and quality of food and cover, succession and gap formation, trophic cascades). A range of options are available to monitor recreation activity remotely, such as asking them to carry GPS trackers (Olson et al., 2018), installing infra-red trail counters on paths (Costello et al., 2013), use of social media data (e.g. through photo identification; Toivonen et al., 2019) and smartphone applications for fitness networks, such as Strava (Rice et al., 2019).

Tracking people, photographing them, and collecting demographic information brings new methodological opportunities and ethical issues for wildlife researchers. Collaborations with social scientists who work on conservation conflicts and with geographical information scientists who have established methods for assessing human movement may strengthen research on outdoor recreation by engaging people who are using the landscape in the study (Miller et al., 2019; Redpath et al., 2013). For example, techniques like participatory mapping with local stakeholders to understand animal impacts on biodiversity and to parameterise models of animal behaviour could be applied to recreational contexts to understand animal-plant-human-interactions (e.g. Austin et al., 2009; Irvine et al., 2009). Finally, as more data on the human activity components are collected, wildlife researchers need to consider the ethical and privacy considerations not only in data collection but in data storage and management (Toivonen et al., 2019).

5. Conclusion

We conducted a systematic review of the literature on studying human-wildlife interactions, in the context of non-consumptive outdoor recreation, focusing specifically on terrestrial wildlife. Our study found a wide range of methods which can be used to study the interaction between terrestrial wildlife and outdoor recreation, and we identified the strengths and limitations of the various methods. We identified temporal patterns in the use of different methods over the past 40 years. Direct observation methods were most commonly used but, increasingly, telemetry and camera traps are being used, reflecting the uptake of modern technologies. Based on our findings, we propose a set of five criteria for researchers to consider when designing studies aiming to capture human disturbance of wildlife from outdoor recreation. Our review and the five criteria we have developed can be used to help researchers to implement good scientific practice when studying how outdoor recreation influences wildlife. We recommend that, in future, greater emphasis is placed on how to capture the human component of this interaction, considering both short- and long-term effects of disturbance on wildlife.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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Appendix A. Supplementary data

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